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ABSTRACT

A study examined the relationship among temporal processing, phonological processing, and reading skill using a multivariate approach which included measures of phonological processing and a variety of timing tasks that have been implicated in timing theories. Subjects were 30 adults classified as disabled readers based on their performance on the Wide Range Achievement Test 3 (WRAT3) and 32 chronological age controls. The reading measures were Form G of the Woodcock Word Identification and the WRAT3 pretest. Phonological processing was assessed using the Woodcock Word Attack and a phoneme and syllable deletion task. A number of timing tasks were used to test the timing deficit hypothesis. Results did not confirm the main prediction of the timing hypothesis, that reading disabled adults would be impaired on tasks with rapid, but not slow processing demands, although the experimental tasks were sensitive enough to reveal group differences between skilled and disabled readers. Findings make it very unlikely that temporal processing deficits underlie the phonological core deficit of reading disability. It is more likely that naming speed deficits are caused by impairments of word-retrieval (or the naming system) rather than impaired temporal processing. (Contains four tables of data.) (RS)

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A Timely Look at the Timing Hypothesis of Reading Disability

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The cause of reading failure may be explained at a variety of different levels. For example, the phonological core deficit may be considered a proximal cause because it provides a causal explanation for reading failure at a cognitive level. In contrast, more distal explanations characterize reading disability at a neurophysiological level or at the level of genetics.

The research I wish to present to you today investigates a hypothesis that may be considered an intermediate causal explanation. This hypothesis, known as the temporal processing deficit hypothesis or timing deficit hypothesis, proposes that impaired phonological processing and reading failure result from impaired temporal resolution. This hypothesis proposes a psychological mechanism that underlies the phonological core deficit of reading failure.

A number of theorists have proposed that an impaired timing mechanism involved in the temporal organization of perception and or action is the cause of reading failure within some subtypes of reading disability. The various theorists do differ, however, in the extent to which they view the deficit as domain specific or domain general. For example, timing deficits may be restricted to audition, audition and vision, or they may be domain general, affecting perception, speech and action.

Although timing theories differ in terms of breadth, they do agree that an impaired timing mechanism will impair disabled readers' performance when there are rapid processing demands, but not when processing demands are slow. Thus,

the timing hypothesis predicts an interaction between speed of processing and reading skill.

Although the various versions of the timing hypothesis assume that impaired temporal processing causes the phonological core deficit, few have directly examined the causal links. The purpose of this study is to directly examine the relationship between temporal processing, phonological processing and reading skill. To do so, we used a multivariate approach which included measures of phonological processing and a variety of timing tasks that have been implicated in timing theories. This approach was used to reveal whether the linkage proposed between timing deficits and the phonological core deficit extends to adults.

Thirty adults were classified as disabled readers based on their performance on the WRAT3. These adults had reading scores below the 26th percentile.

An additional 32 adults were classified as chronological age controls. These adults had reading scores above the 29th percentile on the WRAT3.

The reading measures were Form G of the Woodcock Word Identification, in addition to the WRAT3 reading subtest.

Phonological processing was assessed using the Woodcock Word Attack as a measure of pseudoword reading and Rosner's AAT (Rosner & Simon, 1971), a phoneme and syllable deletion task.

A number of timing tasks from three domains were used to test the timing deficit hypothesis. The domains were: perception, speech production, and manual coordination. The perceptual tasks were: visual and auditory gap detection, and the Seashore rhythm test. The speech production tasks were: the continuous (or list)

version of the RAN, a computer-presented discrete trial RAN, maximum repetition rate, and Syllable Repetition. The motor coordination tasks were: placing pennies in a box, drawing lines and crosses, and the tapping task described by Wolff and his colleagues.

From Table 1, we can see that in addition to having lower scores on each of the word reading measures, this sample of disabled readers displayed the phonological processing deficit that characterizes reading failure, as measured by both pseudoword reading and phoneme deletion. In comparison with a reading-level control group (not discussed here because of time constraints) the disabled readers displayed the classic pseudoword and phonemic segmentation deficits.

The next thing we looked at is whether the timing tasks can discriminate between skilled and disabled readers. In general, the timing tasks did discriminate between skilled and disabled readers. However, the key prediction of several versions of the temporal processing hypothesis concerns the interaction between processing time and reader ability group. All versions of this hypothesis predict that this interaction should be statistically significant. However, the interactions predicted by the timing hypothesis were not significant. In other words, although RD adults tended to perform more poorly on the timing tasks, their performance was NOT influenced by rate. The absence of a rate by reading group interaction contradicts a basic prediction of the timing hypothesis.

A series of regression analyses was conducted using the experimental timing tasks to predict adults' reading performance, independently of phonological processing. In these analyses, the Rosner was forced into the equation as the first

predictor. After the Rosner was forced into the equation, stepwise analysis was used to select the most potent remaining predictors among the timing variables. The results from the two word recognition measures were completely convergent. Once phonological processing had been entered into the equation, the only variable that contributed additional variance to WRAT3 reading was naming speed on the continuous RAN (additional variance explained = .13, $p<.01$). In fact, the combination of the Rosner and the continuous RAN accounted for 54% of the variance in predicting WRAT3 reading performance. No other experimental timing variable contributed additional variance once performance on the Rosner and continuous RAN had been partialled out.

The same pattern was revealed using the Woodcock Word Identification as the criterion variable.

Because naming speed proved to be a very robust predictor of reading skill, a stepwise regression analysis was conducted in which the criterion variable was performance on the continuous RAN. The two variables that explained 48% of the variance of the continuous RAN were WRAT3 reading performance and naming speed on the discrete-trial RAN. Neither performance on any of the other experimental timing measures were predictive of continuous naming speed.

However, one might argue that the other timing variables did not contribute additional variance after the Rosner had been entered because the variance from the timing variables was contained within the variance for phonological awareness. For this reason, the relationships among phonological processing, naming speed, and timing variables was explored using commonality analysis, which allows for

the examination of the unique and common variance that the three measures contributed to WRAT3 reading.

Three composite timing variables reflecting perception, speech articulation, and motor coordination were constructed. A fourth timing variable, timing best, was constructed in order to magnify the variance explained by the timing variable. This variable was based on the timing variables that had the highest zero-order correlations with WRAT3 reading performance.

The relationships between the Rosner, continuous RAN, and Timing-Perception shown in this figure. The 46% total variance in word recognition explained by the Rosner is decomposed into 16.6% unique variance, 5.7% variance shared with timing-perception, and 16.4% variance shared with both the continuous RAN and perception. The 31.5% variance in word recognition explained by the continuous RAN can be decomposed into 7.7% unique variance, 7.3% variance shared with the Rosner, 0.1% shared with timing-perception, and 16.4% shared with both variables. Finally, the 22.2% total variance in word recognition explained by the timing-perception variable is decomposed into 0% unique variance, 5.7% shared with the Rosner, 0.1% shared with naming speed, and 16.4% variance shared with both variables.

Very similar patterns of unique and common overlapping variances were produced among the Rosner, continuous RAN, and the three remaining timing variables.

To summarize, although the experimental tasks were sensitive enough to reveal group differences between skilled and disabled readers, the main prediction

of the timing hypothesis, that RD adults would be impaired on tasks with rapid, but not slow processing demands, was not confirmed. Finally, with the exception of continuous naming speed, the experimental timing measures were not predictive of reading skill. In fact, with the exception of naming speed, the experimental timing measures shared little variance with phonological processing. This makes it very unlikely that temporal processing deficits underlie the phonological core deficit of reading disability.

Although the findings of this study undermine all variations of the timing hypothesis, there are alternative explanations of the data patterns that appear to be more promising. The finding that adult disabled readers name digits more slowly than skilled readers, and that this impairment is a reliable predictor of reading skill independent of phonological processing, is consistent with the empirical findings and theoretical conjectures of Wolf and Bowers. However, our preferred explanation is that our findings suggest that it is likelier that naming speed deficits are caused by impairments of word-retrieval (or the naming system), rather than impaired temporal processing.

In conclusion, our findings show that all versions of the timing hypothesis cannot be used as a causal explanation for reading failure in adults. However, naming speed deficits, in addition to measures of phonological awareness, proved to be a robust predictor of word reading skill. Because naming speed proved to be independent of other timing tasks, it is more likely a reflection of impairments in word retrieval, and not timing deficits. However, it should also be noted that our conclusions must be restricted to the population studied there--that is adults.

Converging evidence from research with children will be needed to further solidify any conclusions, however, particularly since most of the previous work on the timing hypothesis has been done with children.

Table 1.
Reading and Phonological Measures.

	RD	NA
Word Identification	75.2	97.4
	(9.2)	(5.4)
Word Attack	24.4	36.8
	(6.6)	(4.6)
Rosner AAT	22.3	34.4
	(8.2)	(6.1)

Table 2.
Regression Analysis Predicting WRAT-3 Reading Performance.

Step Variable	Mult. R^2	ΔR^2	Partial R	p
Rosner (forced)	.403	.403		<.01
Subsequent Variables (stepwise)				
Continuous RAN (RT)	.535	.132	-.47	<.05
Visual Gap Detection (RT)			.03	ns
Auditory Gap Detection (RT)			-.19	ns
Seashore Rhythm Test			.04	ns
Discrete-Trial RAN (RT)			.13	ns
Syllable Repetition			-.29	ns
Placing Pennies in a Box			-.18	ns
Drawing Lines & Crosses			.01	ns
Tapping			-.22	ns

Table 3.
Regression Analysis Predicting Continuous RAN Performance.

Step Variable	Mult R^2	ΔR^2	Partial R	p
WRAT-3 Reading	.364	.364		<.01
Discrete-Trial RAN	.480	.124	.43	<.01
Estimated IQ			-.03	ns
Rosner AAT			.07	ns
Visual Gap Detection (RT)			.20	ns
Auditory Gap Detection (RT)			.04	ns
Seashore Rhythm Test			.08	ns
Syllable Repetition			-.18	ns
Placing Pennies in a Box			.15	ns
Drawing Lines and Crosses			-.08	ns
Tapping			.00	ns

Table 4.

Commonality Analysis using WRAT3 Reading as Criterion Variable

	Predictor Variables		
	Rosner	RAN	Timing - Perception
Unique Variance	.166	.077	.000
Common Between:			
Rosner & RAN	.073	.073	
Rosner & Timing	.057		.057
RAN & Timing		.001	.001
Rosner, RAN & Timing	.164	.164	.164
Total Variance for Variable	.460	.315	.222

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